Notes on Boiler Testing

BY

FREDERICK GROVER, M.I.M.E., A.M.I.C.E.,

Author of "A Practical Treatise on Modern Gas & Oil-Engines," "Acetylene for Motive Power," &c., &c.

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NOTES ON TESTING STEAM BOILERS.

The following notes on the testing of steam boilers are intended to refer only to such tests as are necessary to examine the economic performances of the boiler, and not to the testing which must be done to ascertain its structural defects. Such tests are no doubt of equal importance as affecting the safety of the community at large, and are generally dealt with by the boiler insurance companies. As far as the purchaser of a boiler is concerned, the question of paramount importance is that it shall raise steam economically. He may be assured by the insurance company that his boiler is safe. Here, however, the responsibility of the company will cease, unless private arrangements are made at additional cost for systematic tests of the boiler under steam with a view to ascertaining its steam-raising qualities. It is to this equally important side of the question that the author desires to draw the attention of large steam users, feeling, as he does, that the subject is not recognised by them as deeply affecting the profits of their industrial concerns. One has only to seek information amongst those who have set themselves to reduce their expenditure in fuel, to learn how much may be done in this direction. Sometimes improvements may be carried out at very small cost. In some instances the writer has been able to effect an economy of 10 per cent of the heat by the mere regulation of the air passing through the flues. Such a process is not costly. To leave the state of the fires to the care of the fireman is likely to lead to serious losses, his only object being to maintain a constant steam pressure and water level. How he does this neither affects

his conscience nor his pocket, and having no knowledge of the science of combustion, he justly feels that he is discharging his duty, which he certainly is, by regulating the abovenamed factors.

Stoking.—In order to illustrate the personal element introduced in good and bad stoking, we may quote the competition which was carried out at Messrs. Davey Brothers', of Sheffield. Five stokers were made to fire the same boiler with the same coal and with the steam pressure about the same. The best stoker was able to obtain an evaporation of 9 lb. of water per pound of coal, the worst evaporation being 7·4 lb. per pound of coal. The difference is here 22 per cent. The opportunities afforded for increasing the efficiency of the boilers were, in this instance, limited. A well-laid fire, which by constant attention is prevented from burning into holes, is one of the chief items in securing a high evaporation. Keeping the fire-bars clean, and regulating the dampers for a maximum quantity of air just after firing contributes greatly to high efficiency. Beyond these points there is little opportunity for exercising skill in stoking, and yet these tests show clearly how very important the simple operations involved in firing a boiler become. The very simplicity is one cause for neglect.

Sources of Waste.—All cases of wasteful steam raising are, however, not so simple as the one we have enumerated. In a large number of cases faulty brickwork is at the root of the evil, and to put this right may necessitate the removal of large parts of the boiler setting, thus interfering with the continuity of the works. In other cases it may be found that a large proportion of the heat is escaping from the boiler flues to the chimney. To remedy this the heating surface of the boiler must be increased. Thus money must be spent on a feed heater if one is not already fitted, or, if it be, a superheater of the type of McPhail and Simpson's—which, by the way, is, in the opinion of the writer, more of a device for extending the boiler heating surface than of superheating, though the

latter may be effected by it when properly arranged. These devices are frequently expensive compared with the cost of their manufacture, because they usually are protected by patent fees, and are therefore a monopoly. That these are in many cases, when well applied, well worth their money, no one will doubt. Unfortunately, however, much mischief has been done by applying the wrong thing to specific evils. To be entirely guided in the choice of apparatus by the vendors of smoke-consumption furnaces, mechanical stokers, and a hundred other appliances, perhaps all good in their proper place, is just as wrong as to apply to a drug store for a prescription. And yet how often is this done! Five minutes' conversation with the enthusiastic representative of a furnace-maker will be quite sufficient to illustrate this point. The conversation is generally as follows:—Interrogator: How is your furnace going?—Representative of enterprising firm: We have this week taken out from Mr. X.'s works no less than four furnaces made by Y. and Company, and put in our own. They are doing infinitely better.—Interrogator: Why are they doing so much better? Messrs. Z. swear by Y.'s furnaces.—Representative: That may be; the firm is behind the times. Nothing can touch our furnaces. Look at these results. (Pulls out table of results, having excluded as incorrect adverse tests, and exhibits figures showing excellent results.)—Interrogator: What were the conditions under which this test, for instance, was made?—Representative: Oh, ordinary conditions—ordinary coal.—Interrogator: Did the feed pump leak at the gland when the test was made? Were the feed pipes blanked off? Was the coal specially dry; and how was the water level at the end of the test?—Alas! the poor representative knows no answer to the questions showered upon him, and therefore fails to secure his order, and goes away feeling some compassion for the ignorant interrogator for not being properly impressed by the figures in which he himself has the faith of an innocent child. The point we wish to drive home in indulging in this digression is that Messrs. Z. swear by Y.'s furnaces because they happen to suit the conditions, whilst Messrs. X.'s adjectives are derogatory to the furnaces because the

conditions were not suitable. The sole reason for this confusion is that people who buy these appliances generally know no more of the inwardness of the things they buy than does the commercial man who sells them. What is wanted to mitigate this unfortunate state of things is more rigorous testing on more scientific lines, and it is with the object of indicating the methods of making such tests and of working out the results that we have undertaken to write the notes which follow.

Heat Value of Fuels.—The function of a boiler is to raise steam with the least possible expenditure of heat. We purposely avoid the expression "expenditure of fuel," because we wish it to be understood that the commercial man is just as much interested in this question of heat efficiency as is the scientific man; and in view of this, the sooner the commercial man becomes accustomed to talk and think of his boilers as heat users rather than coal burners, the sooner will the reforms advocated in the foregoing be realised. Every class of coal has a particular heating value of its own, and when burnt leaves a residue which is termed the ash. Now the heat value and the weight of ash are two factors about which not one manufacturer in a thousand has the slightest regard, and yet they affect his pocket in a very direct way. The total cost of supplying a boiler with fuel is made up of the following items: (1) The cost of the fuel; (2) its cartage to the boiler; (3) the cartage of the ash resulting from the combustion of the fuel to a convenient place for tipping. This latter item is of the utmost importance in crowded towns, where the cost of carting the ash may amount to as much as 3d. or more per ton. Thus it is evident that it may pay in places where cartage is dear to burn a higher class of fuel and secure a greater evaporation in the boiler, at the same time saving in carting ash the additional cost of the fuel. Another point in connection with the value of a fuel is often lost sight of, and that is the percentage of moisture that is contained in the fuel when it is put into the furnace. To illustrate, we will work out the loss of heat on 1 lb. of coal weighed with, say, 7 per cent moisture.

Thus there will be weighed for each pound of coal, 0·93 lb. of actual fuel, and 0·07 lb. of water. Let the heating value of 1 lb. of this coal when perfectly dry be 14,000 thermal units. 0·93 lb. will therefore develop 13,000 units of heat, so that due to loss of weight in the actual weight of coal put on the fires we get a loss of 1,000 units. Again, the moisture which goes into the furnace with the fuel has to be evaporated, and in doing this an additional quantity of heat is extracted from the furnace for no useful purpose whatever. 0·07 lb. of water will require 80 units to raise it to steam at atmospheric pressure. This is the least possible value that we may put to this source of loss, for we are here neglecting the sensible heat due to superheating the steam as it passes through the furnace, and the fact that its specific heat is considerably higher at furnace temperatures than it is at ordinary commeasurable temperatures. The available heat, then, for evaporating the water in the boiler, instead of being 14,000 per pound of coal as we at first assumed, is reduced to 12,920 when losses are taken into account. This represents a total loss of 9·2 per cent on the theoretical value of the dry coal. In general it may be taken as correct that the loss due to moisture is a little less than half as much again as the figure representing the moisture per cent. It is therefore very evident that savings of 10 per cent may be glibly talked about by incompetent testers as due to the application of patent appliances, when the wetness of the fuel is the secret of the entire waste. By drying the fuel before weighing it out for the stokers, 5 per cent may any time be credited to the boiler apparatus. No test, therefore, dealing with small savings of this kind can be considered at all reliable unless the wetness of the fuel be obtained from samples taken as the test proceeds. For those not versed in these matters it is perhaps necessary to observe that the weight of ash which results from the combustion of fuel is always included in the pound of which the heat value is quoted. Thus, when there is 10 per cent of ash we should expect to find the heat value of the fuel low, because per pound it only contains 90 per cent of combustible. Hence no deduction or correction is

needed for the percentage of ash, and it need only be considered in relation to its cost of cartage from the boilers.

TABLE I.—HEATING VALUE OF DRY FUEL PER POUND.

Name of Fuel.	Average Heating Value, Thermal Units.	Theoretical Evaporation per pound from and at 212 deg. Fah.
Nixon Navigation (Welsh)	14,900	15·4
Powel Duffryn, Barnsley slack, Flocton	14,500	15·0
Ordinary Welsh	14,200	14·7
Yorkshire	13,700	14·2
Durham slack	13,600	14·0
Newcastle	13,500	13·9
Denaby nuts	13,400	13·8
Wigan slack	13,200	13·6
Anthracite	12,900	13·3
Gas coke	12,400	12·8
Turf	6,400	6·6

Before describing the apparatus required, and the manner of applying it to boiler tests, it will be well to traverse briefly the underlying principles of economic stoking, so that those unacquainted with the subject will understand the importance of the points to which we shall direct attention.

Combustion.—The constituents of coal vary greatly, and the proportions will be found to lie between the following extremes: Carbon, 70 to 90 per cent; hydrogen, 2 to 7 per cent; oxygen, nitrogen, and sulphur, taken together, 3 to 10 per cent; ash, 3 to 12 per cent; and moisture, 1 to 5 per cent. The constituents of the coal, of course, determine the air supply necessary for its com-

bustion. In round numbers it may be taken that from 10 lb. to 12 lb. of air are required per pound of coal to convey just the necessary quantity of oxygen to it for its complete combustion. In practice this figure is always exceeded, and will be found to vary from 17 lb. to perhaps, in extreme cases, 30 lb. of air per pound of coal, the latter figure resulting in enormous waste of heat, as we shall presently see. Some coals are known to produce dense volumes of smoke when first put upon the fires. This is due to the rapid distillation of the hydrocarbons, and when a fuel is rich in these constituents it will generally follow that smoke is difficult to prevent. We do not say that it cannot be prevented, but we do say that in many cases it is prevented at great loss to the consumer. It is quite false to suppose that the loss due to the emission of dense smoke from a chimney is seriously prejudicial to economy. We do not exaggerate when we state that the loss will be ten times as great if the smoke be prevented by increasing the air supply, and this for the simple reason that the air supply is seldom regulated judiciously. When coal is burnt, a certain amount of air must pass *through* the grate bars and a considerable amount should pass *over* the fires. All the air that enters the furnace has first to be heated to the temperature of the fires; the resulting gases then pass along the flues, the heat is absorbed, and water is evaporated. The gases leave the boiler at a temperature of, say, 600 deg. Fah., and each pound of gas carries with it about one unit of heat for every $4\frac{1}{2}$ deg. of temperature. It is important, therefore, that the weight of air be minimised to the greatest possible extent. If, however, this is carried too far, the combustion becomes incomplete, and is shown to be so by the lambent blue flame which burns where the gases meet any additional supply of air. This characteristic flame is due to the burning of the carbon-monoxide, and when the combustion of this gas takes place in such a position that its heat cannot be transferred to the boiler plates there is considerable waste. It will be observed that too much or too little air is fatal to the economic working of a boiler, and we shall now show how by an analysis of the flue gases the waste may be determined.

The Chimney Gases from an ordinary boiler will, upon analysis, yield the following constituents in variable proportions according to the air supply:—

> Carbon-dioxide (CO_2), from 16 to less than 5 per cent by volume.
> Carbon-monoxide (CO), from 2 per cent to none; generally none.
> Free oxygen (O), from 12 to 3 per cent.
> Nitrogen (N), from 79 to 81 per cent.

In a complete analysis a small percentage of sulphur and other impurities would be obtained, but such quantities are small and do not affect the question of air supply. The composition of the chimney gases and their fluctuation in volumetric proportions will be easily followed by reference to Fig. 1. Suppose the line *a b* to represent a volume of chimney gases, and that a minimum quantity of air

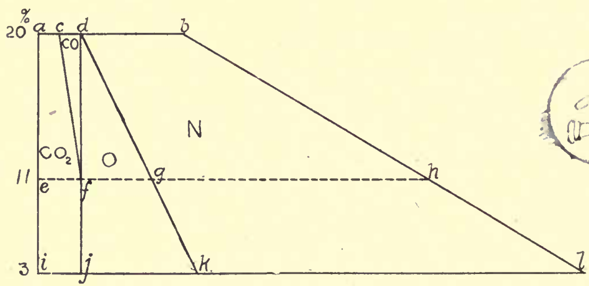


Fig. 1.

has been admitted to the furnace per pound of coal. Under these circumstances a large percentage of CO will be formed—that is, a large volume of gas will be formed which would burn with the development of much heat, provided it was supplied with more air. As, however, this air by supposition is not forthcoming, the CO passes into the flues and ultimately reaches the chimney top. In the diagram before us the CO is represented by the line *c d*. Some carbon-dioxide will be present, and this is represented by the line *a c*. The residue of nitrogen is represented by the line *d b*. Thus in this theoretical example we have no oxygen present, because we have supposed that an insuf-

ficient amount of air has been admitted and that all the oxygen has disappeared in forming CO and CO_2. Let the air supply be now increased so that there is more oxygen than is theoretically needed for the combustion of the fuel. The result will be that the CO decreases, while the CO_2 increases, and free oxygen begins to show itself. This proceeds until all the CO disappears, its place being then occupied by the CO_2 indicated on the diagram by the line *e f*. The lines *f g*, *g h* represent respectively the free oxygen and nitrogen. Now, the heat liberated in burning fuel to CO is about 4,500 units, as against 14,000 if burnt to CO_2. Hence the area marked CO represents a serious loss due to imperfect combustion. On the other hand, a large additional volume of air must pass through the furnace to reduce the CO. This loss is more than compensated for by the gain due to more perfect combustion. At *e f* (Fig. 1) we have accomplished the perfect combustion of the fuel, and the actual volume of the CO_2 formed per pound of coal must now remain unaltered, no matter how much more air is supplied. The line *i j k l* shows a further increase in the air supply. From this it is at once apparent that whereas *e f* represents about 12 per cent of *e h*, *e f* or *i j* represents only 8 per cent of *i l*. The percentage of CO_2 is at once an index of the excess of air passing through the furnace. The percentage of CO affords a second index of the loss of heat due to imperfect combustion. The problem which we have to solve is represented graphically on the diagram, and may be thus stated: How large may *e f* be in proportion to *e h* without the formation of CO? Theoretically *e f* might approach 20 per cent of *e h*, but this is impossible under the conditions of a boiler furnace, and if it reaches 16 per cent in a locomotive boiler, or 13 per cent in a Lancashire boiler, the result is considered excellent.

Air Supply.—Fig. 2 shows the weight of air per pound of coal for an average fuel and the percentage of CO_2 which will be present in the gases with the various quantities of air. Thus the horizontal dotted line at 10 means that with 10 per cent of CO_2 the air supply would be little

less than 23 lb. of air per pound of coal. We shall show later how to work out the weight of air per pound of coal, which must vary with the fuel analysis; the diagram, however, depicts the quantities with sufficient accuracy to enable the reader to form a clear idea as to the weight of air present with a given percentage by volume of CO_2.

Heat Loss due to Air.—Fig. 3 shows at a glance the loss of heat per cent in heating the air which passes through the fires on the assumption that $11\frac{1}{2}$ lb. of air are required theoretically, and on the further assumption that the temperature of the chimney gases is 600 deg. Fah. It will be seen that there is, under theoretically perfect

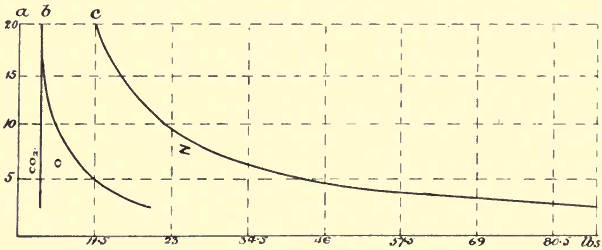


FIG. 2.

conditions of combustion, an inevitable loss of nearly 10 per cent of the heat. This occurs even if the percentage of CO_2 is as great as 20 per cent, which is, of course, impossible to attain in steam boiler furnaces. The slope of the curve begins to increase rapidly with less than 10 per cent of CO_2. There is an interesting point in connection with the slope of the curve which we shall refer to later. At the present let it be noted that the slope of the curve at any point represents the rate of loss of heat compared with the rate of alteration of volume of the CO_2. Thus with 15 per cent CO_2 the rate of loss is represented by the tangent of the angle of slope, the value of which may be scaled off as 2·75. Now take another point on the curve at, say, 8 per cent of CO_2, and draw the tangent. Here the slope measures 9·75. Thus at 15

per cent CO_2 we see the smallest possible decrease in the volume of CO_2 results in a loss taking place at the rate of 2·75; whereas a small decrease in the percentage of CO_2 in the region of 8 per cent results in a rate of loss represented by 9·75, or three and a half times greater than

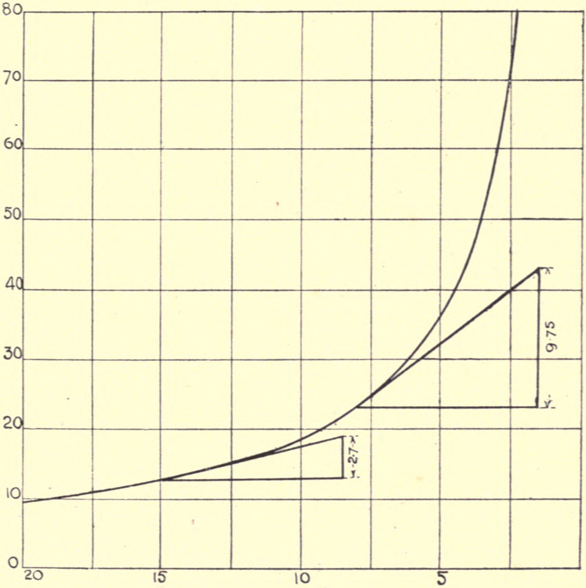


Fig. 3.

at 15 per cent. When using the volume of CO_2 present in the furnace gases as an index of the heating efficiency, this point should be carefully remembered.

The losses exhibited on this diagram, Fig. 3, are solely due to excess of air, not to the formation of (CO) carbon-monoxide. In order to present some idea of the losses due to the formation of CO we have prepared the diagram Fig. 4. In calculating the figures from which this curve has been plotted, it has been assumed that there may be

a gradual interchange between the weights of CO and CO_2 obtained by burning the same weight of fuel. The horizontal line gives the minimum loss of heat with 20 per cent of CO_2. This is merely transferred from Fig. 3. The additional loss of heat due to the formation of CO is therefore given by the intercept between the dotted line and the curve of Fig. 4. As an example, suppose an analysis of the furnace gas yielded 11·6 per cent of CO_2 and 1·05 per cent of CO. From Fig. 3 we find 18 per

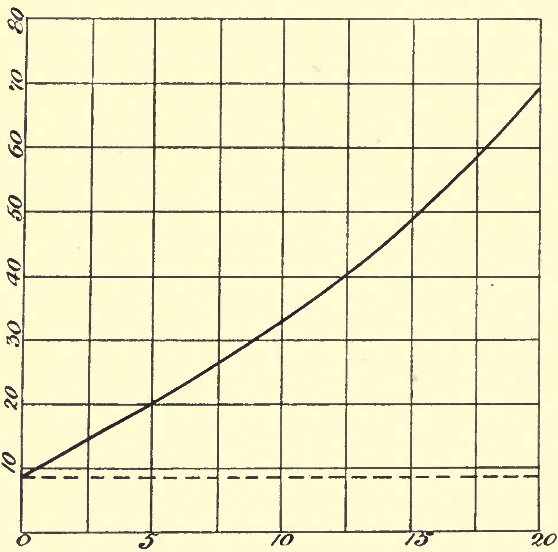


Fig. 4.

cent loss due to excess of air, and from Fig. 4 we have 2 per cent loss due to the formation of CO, giving an aggregate loss of 20 per cent.

From the preceding it will be apparent that the two sources of loss to be guarded against in the firing of a boiler are, firstly, that due to the excess of air; and secondly, that due to the deficiency of air resulting in the

formation of CO. The problem may, and often does, arise—Does it pay to decrease the air supply at the risk of forming CO? The problem is best answered by an examination of Figs. 3 and 4 combined as in Fig. 5. It will be seen that the curve which represents the loss due to CO is nearly straight, and its slope is therefore nearly constant. The curve of the CO_2 losses is nearly parallel

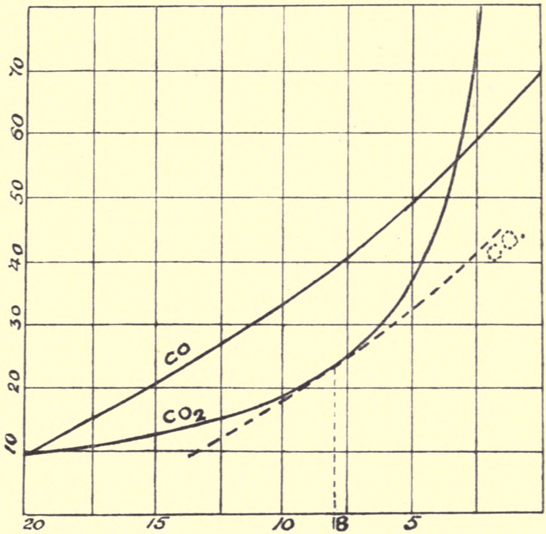


FIG. 5.

at about 8 per cent of CO_2. Thus it appears that the rate of loss due to any alteration in the volume of CO_2 at or about 8 per cent of CO_2 is the same as the loss due to any alteration in the CO. Consequently if a slight diminution in the air supply resulted in the formation of CO, the gain due to the reduction in the air supply would be balanced by the loss due to the formation of CO. To the right hand of this point on the diagram (namely, 8 per cent CO_2) the loss due to the excess of air exceeds that

due to the formation of CO; hence it would pay with less than 8 per cent of CO_2 to reduce the air supply at the risk of forming CO, and if CO were formed the loss would be less than that occurring with the extravagant supply of air.

PREPARATIONS FOR TRIAL.

Defective Brickwork in Flues.—In making preparations for a boiler trial a preliminary survey of the plant should be made. Drawings of the boiler setting should be examined, and any peculiarities of the form of grate bars specially noted. When a boiler is working without any forced-draught appliance, it is advisable to test the draught at the point where the flue leaves the boiler, and again at the ashpit or some convenient place just beyond the furnaces. This may be done by means of a glass U tube half filled with water. A flexible pipe attached to one end of the U, and having its other end attached to an iron pipe inserted in the draught hole, will suffice. The object of taking the draught is to form an opinion as to the state of the brickwork—whether leaky or not. The brickwork of old and sometimes new settings may be found to be in a very defective condition. When this is the case it is little use attempting to carry out a successful trial. Under such conditions the best results cannot be expected. The author has frequently found it necessary to have the entire brickwork overhauled before anything could be done. Sometimes it is considered sufficient to plaster the brickwork over with gannister. This is not generally satisfactory, for in a short time the gannister becomes dry and falls off. Ordinary mortar or cement is for the same reason of little use, and when the settings are generally defective, no amount of patching will remedy the case. Some bricks are themselves extremely porous, and may therefore leak to a great extent, notwithstanding that the joints are apparently in good condition. The best, then, that can be done with faulty brickwork before a test is to lute up all visible cracks with gannister, and to see that it is well rammed into the crevices to prevent it falling away when dry.

Feed Arrangements.—The boiler to be tested should be fed from a separate feed pump with the delivery pipe entirely detached from other feed pipes. In nearly all works one donkey pump supplies two or three boilers by means of a common delivery pipe. Valves are provided at the boiler inlet to regulate the feed to each boiler. No reliance should be placed on the valves. They may suit their purpose admirably as a means of regulating the amount of water that passes them, but they seldom completely shut off the supply of water. It is therefore of the utmost importance that the feed pipe of the boiler under test be entirely blank-flanged from all other connections. On one occasion a boiler test was made to record results which were supposed to be remarkable. The preliminary tests which led eventually to the official tests were made with the feed-pump delivery pipes attached to several boilers, and the valves were screwed down to shut off all other deliveries of the water. The evaporation, as obtained by the preliminary tests, was said to be over 11 lb. of water per pound of coal. When the official test was made, all precautions in respect to the feed arrangements were taken, with the result that the evaporation was not much more than 9 lb. per pound of coal. The difference may have been partly due to atmospheric conditions, but it was undoubtedly chiefly due to the leakage in the first test being credited to the evaporation.

Measurement of Feed.—The arrangement for the measurement of the feed water is necessarily largely decided upon to suit local conditions, and for this reason no hard-and-fast rules can be laid down. The following arrangement must, however, be carried out in principle, if not in detail. The arrangement shown in Fig. 6 has been designed with the object of minimising all possible errors. The design of the testing plant to secure this is of the utmost importance, because the person in authority on the test cannot supervise in detail every measurement, and he is frequently provided with assistants who are unaccustomed to taking accurate measurements. In cases where the measurements can be made to some extent automatic, the advantage of

such should be secured. It will be found in the following that the person measuring the feed has only to fill a tank until it overflows. He then waits until the drip from the tank has ceased, when he is able to open a valve and admit the water into the pump tank, at the same time making a proper record of the fact. To trust an unskilled assistant to read correctly the height of a column of water against an inch scale is quite fatal. Although such a statement may appear ridiculous to those who have never attempted experimental work, it is nevertheless a fact that such work presents difficulties which only training can overcome.

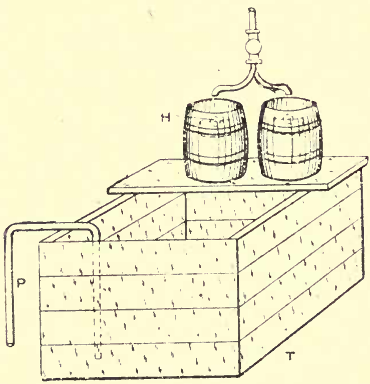


FIG. 6.

To quote Professor Kennedy ("Physical Experiments in Engineering," Inst. Civil Engineers, vol. cxxvi., page 317), "Perhaps those whose work lies greatly in experimentation, like my own, know best how very hard it is to find assistants, unless they have been trained in a laboratory, who can be trusted at first even to take quarter-hourly readings of a steam gauge or a counter, or any such duty, ridiculously simple and easy as it appears. To ask an untrained man to count the revolutions of an engine which has no continuous counter attached, or to read the dial of an ampère-hour meter at exactly regular intervals of time, is merely to court disaster."

The lower tank T should be chosen with some regard to the quantity of water to be pumped into the boiler in a given time, and also with regard to the size of the upper measuring tanks. With the feed pump continually working, the lower tank should be a sufficient reservoir to draw upon whilst the upper tanks can both be filled from the water service pipe. If all went well during the test it would be sufficient if the lower tank lasted only while one upper tank was filled; such an arrangement leaves no margin for temporary breakdown of the gear, and is not, therefore, advisable. For temporary purposes the lower tank may be made of inch boards, the edges of which should be planed and a narrow groove cut in them with a circular saw. These grooves should be filled with white lead, and a strip of hoop iron driven in to a distance of half its width. When two prepared boards are put together, the projecting strip enters the groove on the edge of the other board, and so makes a tight joint. The lower tank should be supported upon packing a few inches from the ground, so that it may at all times be examined for leakage. It will be evident that any water which leaks from this tank is counted as entering the boiler, unless the extent of the leak is measured and deducted from the total feed. The pump suction is taken from the bottom of this tank either by a syphon pipe P or flanged connection. The upper measuring tanks should be of the same capacity, and have well fitted screw-down cocks placed so as to entirely drain the water from the tanks. The holes H should be not less than 2 in. in diameter, and should have a brass plate fitted horizontally across the diameter of the hole. The position of the holes and the plate should be obtained in the following way. Suppose the capacity of the upper tank when filled to within a few inches of the top be, say, 500 lb. Place the tank upon a suitable weighing machine, and balance the machine with the tank on and levelled up by means of a straightedge lying upon marked points on the upper edge of the tank. This done, put the jockey weight of the steelyard to the 500 lb. (if that is to be the quantity of water to be measured at each operation of the tank), and run in the water until

the balance is again restored. Mark the height at which the water stands on the inside of the tank, and proceed to cut a hole of, say, 2 in. diameter, having its centre at the water level. Having procured the brass plate, fix it at the measured position of the water level in such a way that an increase in the height of water results in its flow over the brass plate. The edge over which the water flows should be sharp and perfectly smooth. When the plate is screwed in position again, fill up the tank to check the level. It is best to put the plate across the hole rather higher than is thought necessary. This permits of it being filed down to exactly the correct position with the water in the tank. Having calibrated the tanks in this way, they may be removed to the suction tank and supported above it in the manner shown in the sketch. Great care should be taken that the levelling of the tank should correspond with that on the weighing machine. And, further, it should be arranged that none of the drippings from the tank should be allowed to find their way into the lower tank. If such be allowed, the water pumped into the boiler will be in excess of that measured, and lead to serious error.

Feed Pumps v. Injectors. — It not infrequently happens that an injector has been used for feeding the boiler, instead of a feed pump. In this case it is desirable to replace the injector with a pump. The former is not satisfactory, in that it leads to trouble in two directions. Firstly, the flow through an injector is not capable of regulation. Either the injector must be off or on; and when thus worked intermittently, as is nearly always necessary, the boiler water level is constantly fluctuating, together with the steam pressure. Secondly, provision has to be made for measuring the overflow from the injector. Although this is easily done by coupling the overflow to the suction tank by a rubber hose pipe or other convenient means, the arrangement is not satisfactory. In this connection it may be pointed out that some of the following troubles may arise when an injector is used for feeding a boiler under test. Possibly the tank supplying

the injector, which we have above referred to as the suction tank, may be at a much higher level than the injector. With some injectors this leads to difficulty in getting them to work when the overflow discharges into the suction tank. Then, again, it sometimes happens that the supplementary overflow pipe is full of water, and a rush of steam blows through the overflow. This invariably leads to the hose pipe giving out at its joint with the injector. Of course, all these difficulties may be avoided by very carefully handling the apparatus, but it is not wise, in conducting any important tests, to rely too much upon either good management by subordinates or good luck. Sometimes, in order to avoid all possibility of failure of an injector, it is previously sent to the makers, who test it and return it in perfect order. That injector when put into position on the boiler may refuse to do its work, and may have to be discarded at the eleventh hour. The reasons for this may be various. Sometimes the injector itself gets sprung in making the joints, sometimes a careless fitter allows red lead to be squeezed into the injector, sometimes a check valve is found to be stuck, and sometimes the feed pipe becomes choked near the boiler. Such are the contingencies to be faced, and it is because of these that the boiler should be previously worked with all its fittings as they are intended to be for the test.

Water Level in Boilers.—The water level during boiler tests should be kept as constant as possible, and for this purpose it is necessary to fix a scale to the gauge glasses. When two gauge glasses are fitted to the boiler, both should have the scale fitted, so that in the event of accident to one of the glasses the other is there to fall back upon. For the scale, a strip of paper ruled to inches and tenths of an inch should be pasted upon a piece of wood cut to fit in between the gauge mountings. The height of the water should be taken at the commencement of the trial and at regular intervals of quarter hours. The observations thus made should be passed on to the person in charge of the feed pump, so that he may regulate the

feed accordingly, and so maintain a constant water level. Whether this can always be done depends, of course, upon the demand for steam. Sometimes the sudden demands for steam—as, for instance, when steam hammers are intermittently in use—considerably reduce the steam pressure and water level. For this reason it is preferable, when possible, to run the works at a constant load, or to disconnect the steam supply and blow to waste—an arrangement which does not readily appeal to the works manager. The ideal way of taking the readings of the boiler level is to have the scale calibrated to read directly therefrom the number of pounds of water in the boiler at any time. This involves considerable trouble, as the boiler must be emptied to the lowest level of the gauge glass and filled up by measured quantities. In practice this can seldom be done, and it is therefore of the utmost importance that the level of the water in the boiler be the same at the end of the test as at the beginning. It is not satisfactory to rely upon the calculated weight of water in excess or otherwise, although it is a good plan to state in reporting the test what error there might be in the evaporative results by an alteration of, say, one-tenth of an inch difference in level. As a rule the test should be of such duration as to bring this error to a negligible quantity, for no one can rely upon reading a boiler gauge to nearer than one-tenth of an inch, and this for the simple reason that the water in the boiler is not quiescent at its surface.

Fuel and Water Used to be Plotted as a Curve.—The weight of fuel used is as important as the feed-water measurements. It should be noted in connection with both the water and fuel measurements that any error made during the tests cannot be rectified. It can only be surmised in plotting the results that a hundredweight of fuel was not counted, or that a tank full of water was neglected—in other words, all these measurements are cumulative, and the error once made is lost sight of. In other observations — such, for instance, as the pressure gauge reading, or the flue temperature reading—sudden

fluctuations are unlikely; and even if erroneous readings be taken, the average is not so greatly affected when such an error is divided by the total number of readings.

Measurement of Fuel Used.—The fuel should be weighed upon accurate scales in lots of, say, 1 cwt. at one time. When possible the weighing scales should be placed quite apart from the firing floor, and the weighed fuel conveyed in sacks to the fireman. The time at which each sack is passed over to the fireman should be noted, and each sack should be booked when the fireman *receives* it. At the end of the test any fuel left over is returned to the scales and discounted from the last sack supplied. It is easy to make mistakes in this simple performance. Suppose, for instance, that the assistant in charge of the fuel is relieved from his duties for some little time, and his deputy commences to book the sacks as they are burnt instead of at the time of handing them over to the stoker. During this interim it is obvious that one sack is counted twice over. This same remark applies to the water readings, and should not be despised. On one occasion an error of the water readings of 1,000 lb. was made by this oversight, but was fortunately detected in time to permit of its immediate correction.

Samples of Fuel.—A bottle with a glass stopper should be provided for sampling the fuel, and into this bottle a small quantity of the fuel from each hundred-weight should be placed, the stopper being inserted in the bottle after each sample is taken. This precaution is necessary to prevent the evaporation of moisture from the coal in the event of the samples becoming very warm, as they are apt to do in the stokehole of a boiler. The effect of wetness of the coal may be very marked, and error in the evaporative results will tell to the disadvantage of the boiler if the fuel should during the test become artificially dried in the sample bottle. The sample of fuel should ultimately be ground to a fine powder and thoroughly mixed before it is analysed.

Rate of Combustion.—It is important that the rate of combustion of fuel be as uniform as possible. The choice of rate will be influenced by the following considerations. The object of the tests may be to ascertain the maximum efficiency of the boiler, or it may be desired to evaporate a certain quantity of water in a given time. With regard to the first condition, let it be supposed that, regardless of all other practical conditions which might be imposed in actual work, it is required to determine what the maximum efficiency of the boiler is, regarding the latter only as a means of conducting the heat derived from the fuel to the water. Commencing with the furnace, we have seen that the chief source of loss is due to the admission of excess of air. This may be diminished by thickening the fires or by reducing the draught. The latter can only be done by lowering the dampers; but it is frequently found that the dampers are not sufficiently airtight to make much difference to the draught at the ashpit, nor is the volume of air very greatly diminished. The maximum effect of the dampers may have been realised, and the fires may have been so far thickened as to bring about the economic combustion of the fuel; but when this is done it may lead to too rapid production of steam or to dropping of the firebars due to excessive temperature. There is then no alternative; the grate area must be reduced and a smaller volume of fire kept upon the grate. In dealing with locomotive boilers and other types fitted with return smoke tubes, it is seldom advisable to reduce the draught, as this leads to a great reduction in the velocity of the gases passing through the tubes, and this is known to be detrimental to the free transmission of heat to the water in the boiler.

Clean Flues.—Having as far as possible arranged the furnace to secure the best conditions, it is necessary to inquire into the heat-absorbing capacity of the boiler heating surfaces. These should be thoroughly clean, or no fair test can be made. From 15 to 20 per cent efficiency may easily be lost by dirty flues and by greasy deposits on the inside of the boiler. Indeed, serious greasy deposits

in the neighbourhood of high temperatures will soon prove disastrous. The heat loss is that carried away from the heating surfaces as the gases pass away to the chimney. It is therefore obvious that their temperature should approach that of the steam in the boiler. It must here be remembered that we are dealing only with boiler efficiency, and not with the combined efficiency of a boiler and economiser. Theoretically the temperature of the chimney gases should be such that upon leaving the heating surface no further transfer of heat is possible. Beyond the general principle that low temperature of chimney gases should lead to economy, no definite data can be given. The variety of conditions in the various tests recorded render it impossible to estimate with certainty the effect of variations in the temperatures of the gases. Thus, for instance, we find a difference of temperature between boiler steam and flue gases of 170 deg. accompanied by an efficiency of over 80 per cent. Again, a difference of 114 deg., which should give a higher efficiency, only yields a result of 67 per cent. It is worth noting that the leakage of air into the flues is often responsible for the low temperature of the gases, and such may be the cause of the discrepancies referred to. It is reasonable to expect very good boiler efficiency with a flue temperature (measured at the end of the heating surface) of 150 deg. Fah. above that of the steam in the boiler.

Commercial Economy. — Referring now to the secondary object of a test—namely, how much water may be evaporated in a given time regardless of efficiency: These tests generally arise from the desire to burn a cheaper fuel, and it is easy to see that commercial economy may result from the use of a very cheap fuel, even though its use may be accompanied by very low boiler efficiency. To burn a cheap fuel some form of forced-draught appliance is generally required, and the thickness of the fires should be restricted. The point at stake in such instance is generally to ascertain whether the boiler will be equal to the demand upon it when the fuel is of an inferior order, and therefore much cheaper. The fires must be frequently

cleaned, and the force draught must be sufficient to burn the fuel easily. The evaporation of the boiler will increase with the weight of coal burnt per hour, though not at the same rate, for the more coal burnt the greater must be the forced draught, and a time will come when an intense heat may be secured within the mass of burning fuel, which, however, is chiefly dissipated in heating the great excess of air passed through the furnace.

Quality of Steam Produced. — When steam is generated it passes from the turbulent surface of the water as saturated steam. During its transit it may entrain with it a certain amount of water in a finely-divided state. This action is most likely to take place when the demand for steam is beyond the legitimate capacity of the boiler, or when the surface of the water is too near the exit of the steam from the boiler. If moisture be present in the steam from either of these causes, it is evident that 1 lb. weight of feed water cannot be said to be *evaporated* merely because it disappears from the boiler, for it is possible that owing to the above causes one-tenth of that pound may exist as water at the temperature of the steam, and only nine-tenths may have been evaporated. Thus, suppose steam of 100 lb. per square inch absolute pressure, its temperature will be 328 deg. Fah. This will be the temperature of the entrained one-tenth weight of water, and in order to convert this weight of water into steam it will require an addition of 88·4 units of heat. This addition represents 7·4 per cent of the total heat of 1 lb. of steam at 100 lb. pressure. This heat is not added to the entrained water, and remains to assist in the evaporation of a second pound of feed water. Thus the boiler may be erroneously credited with the evaporation of one-tenth more water than is really the case, and this affects the heat account by apparently raising the efficiency 7·4 per cent. From these figures it is apparent that any test professing to give the actual efficiency of a boiler in which no account of the steam dryness has been taken is apt to mislead. A boiler which primes heavily will be falsely credited with a high efficiency. When the steam has left

the boiler it is liable to condensation in the steam pipes. The condensation takes place with the formation of a slight mist, resulting in the transit of fine particles of water, together with the steam, to its destination. Possibly the condensation continues, and the increasing globules of water ultimately fall to the bottom of the containing vessel. This secondary cause of wetness is of no account in connection with a boiler trial, for it would not affect the results if the whole of the steam became condensed, provided such condensed steam did not drain to the boiler, to be re-evaporated. This secondary wetness is frequently a source of error, for it is often forgotten, and the sample of steam tested for priming effects is vitiated by secondary condensations in the steam pipes. It is not advisable to rely upon well-clothed steam pipes for preventing condensation. More especially is this the case when the velocity of the steam is slow, as is frequently the case in the main supply pipes. The wetness has been affected by as much as 10 per cent by altering the velocity of the steam in the pipe. These facts being of the utmost importance, the following rules may be laid down for the position of the sample hole for collecting the steam for determining the wetness. When the boiler is the subject of the test, the steam should be collected quite close to the boiler, from a sampling pipe inserted across the centre of the steam pipe, and drilled with $\frac{1}{4}$ in. holes to face the steam current. In the event of testing the quality of the steam as supplied to an engine, the sample should be collected quite close to the engine. Care should be exercised in efficiently draining the steam pipes of secondary condensed water when the main steam pipes are arranged to drain back to the boiler. This method of draining the pipes, though frequently resorted to, is not good, for it is likely to lead to serious water-hammer action in the steam pipes. Suppose, for instance, that a long length of pipe terminates with the boiler stop valve, and that this pipe gathers water during its disuse from steam leakage from other sources: the condensed water becomes banked up at the boiler stop valve when the latter is closed. Immediately this boiler is put into operation and the stop valve

opened, a mass of water is projected forward by the on-rushing steam. The result of the impact of this water at the first bend it meets in the pipe will in all probability break the joint or fracture the pipe. The rate of condensation in steam cast-iron pipes which are well lagged, and in which the steam is not moving, has been found to be about one-quarter of a pound per square foot of inside surface of the pipe per hour. In one instance a cast-iron pipe of 3 in. bore, clothed with haybands $1\frac{1}{2}$ in. in thickness, condensed 0·27 lb. of water per square foot of inside surface of pipe per hour. The pressure carried by the pipe was 40 lb. per square inch.

Measurement of Wetness of Steam.—Boiler experts are generally agreed that no known form of calorimeter is entirely satisfactory, and that all forms require the greatest care and discrimination in order to obtain accurate results. The reader who wishes to examine for himself the possibilities of the many forms of calorimeter already proposed can best do so by reading Professor Unwin's report to the Institution of Mechanical Engineers, which will be found either in the Proceedings of the Institution, or in the *Engineer* of August 24th, 1894. For our present purpose we shall confine our attention to two forms, one of which may be used when the degree of wetness is not great, and the other for any determination of either wetness or superheat.

Three principles are made use of in determining the wetness of steam. First and least satisfactory is the chemical method. If common salt or any other soluble matter be placed in the boiler it will remain there unless mechanically carried over in solution with water entrained in the steam drawn from the boiler. The condensed steam may be tested for saltness, and when the total volume of water in the boiler is kept constant, the degree of saturation of the boiler water may afford a check on the determination. This is one of the first methods ever used in steam calorimetry, but it presents so many obstacles to accuracy that it is now abandoned. Firstly, it is obvious that only water which is mechanically entrained with the

steam contains the detective soluble substance, so that secondary condensation escapes notice, hence this method is useless for engine tests. Secondly, the degree of saturation of the boiler water is not uniform, being at a minimum near the incoming feed water, and a maximum where the circulation is least brisk. For these reasons preference is given to the condensing method.

When a pound of dry, saturated steam at a given pressure is condensed by a known weight of water of which the temperature has been previously ascertained, it is possible to calculate the resulting temperature of the mixture. For this calculation the data required are obtained from Regnault's classical researches on the temperature of steam and its latent heat at various pressures. If the resulting temperature above referred to falls short of that expected from saturated steam, we know that there must have been present a certain amount of water which has robbed that pound of steam and water of some of the latent heat. Suppose, on the other hand, that the resulting temperature of the mixture of condensed steam and water is higher than that calculated from the steam tables, it is apparent that some superheat has existed. This method involves careful observations of the weight of steam condensed and the pressure at which it enters the condenser, and of the weight of the water used for condensing the steam and its temperature before and after condensation has been effected.

Before describing the apparatus in detail for carrying out the experiments we will briefly traverse the principles underlying the use of the throttling calorimeter. If a pound of steam at the pressure P be allowed to expand without doing work, to a lower pressure p, its temperature will momentarily rise, because it contains more heat at the higher pressure P than is needed to form saturated steam at the lower pressure p. If, however, the original pound of steam contains water in suspension, the surplus heat will evaporate the water at the lower pressure p, and after evaporating all the moisture will then superheat the whole of the resulting steam.

It is necessary, of course, after the expansion of the

steam and the consequent re-evaporation of the suspended moisture, that a degree of superheat should exist. The necessity of this condition at once imposes a limit on the use of the instrument, it being now apparent that very wet steam when expanded will not result in a superheated mixture. We shall touch upon this point again in describing the apparatus by which the experiment is carried out.

A Condensing Calorimeter may be arranged in the way depicted in Fig. 7. Here the tank B contains the supply of cold water, and is mounted upon scales which

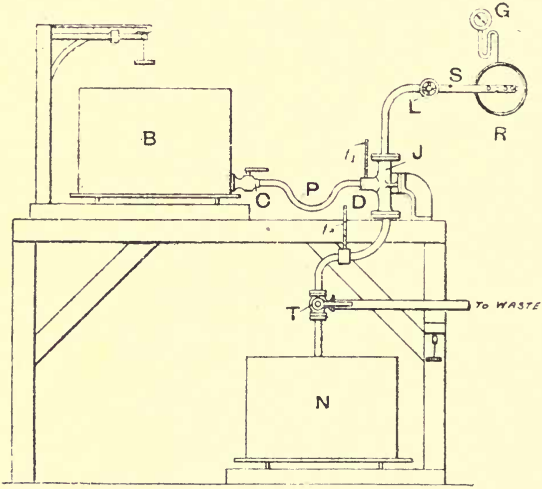


FIG. 7.

will weigh to at least within $\frac{1}{2}$ lb. in 100 lb., and thus the moisture will be determined within the half of 1 per cent. (See below error involved in thermometer readings.) The cold water flows from the tank B through a pipe P, which should be of flexible rubber, but securely wired to the outlet tap C from the tank B, and to the branch D of the

injector J. The two thermometers are required for measuring the inlet temperature and outlet temperatures of the water passing through the injector. In order to secure the same degree of accuracy as above mentioned, the thermometers should read to the fifth of 1 deg. Fah. The steam to be tested is collected in the pipe S, which is inserted in the steam pipe R. An accurate pressure gauge should be arranged to give the pressure of the steam in the steam pipe close to the sampling pipe. The accuracy of the steam gauge is of less importance than the other readings, because the total heat of the steam increases slowly in comparison with the increase of pressure. The steam and water, after mixing in the injector, pass to the lower tank N, where a second record of the weight must be made. This measurement will differ from the weight of water passed from the upper tank by the amount of steam added as the mixture passes through the injector. A cock L should be provided for admitting the steam to the injector, and it is important that this cock should be of equal bore to the inlet pipe to the injector. Any throttling of the steam as it passes to the injector from the main pipe will, of course, tend to dry the steam. A large cock should be provided for convenience in emptying the lower tank. Before commencing an experiment the apparatus should be worked until all the parts have reached a normal working temperature. The cock T should be arranged to permit of the injection of water either running to waste or being discharged into the lower tank.

When about to make an experiment, set the scale beam of the upper scales to lift at, say, 300 lb. of water. Fill the tank up to the top. The extra weight thus put in will allow of a running start being made. Balance the lower tank, and set the cock to run to waste. Turn on the water to the injector, and secondly open the steam to the injector. When the injector is found to be working satisfactorily, the steam cock should be full open. Now watch until the upper scale beam just begins to rise, then shut off the waste and discharge into the lower tank. The upper tank should be nearly emptied, and during the time this is taking place several readings of the inlet and outlet

thermometers should be taken, and from them the average for each ultimately obtained. Considerable practice will be required in making a running start in the way here described.

The quality of the steam may be determined by the following calculation:—

Let W_1 = weight of water taken from tank in a given time.

W_2 = weight in lower tank in same time.

w = weight of steam passed into injector = $W_2 - W_1$.

t = temperature of steam.

t_1 = inlet temperature of injector water.

t_2 = outlet temperature of injector water.

x = dryness fraction.

$\frac{1}{x}$ = weight of water entrained with steam.

L = latent heat of steam = $1116 - 0{\cdot}71\,t$.

Then the heat given up to the condensing water = heat extracted from steam sample.

Heat given up to condensing water = $W_1\,(t_2 - t_1)$.

Heat extracted from steam $= w\,x\,L + w\,(t - t_2)$

$= w\,(x\,L + t - t_2)$.

But $W_1\,(t_2 - t_1) = w\,(x\,L + t - t_2)$;

$$\therefore x = \frac{\frac{W_1}{w}\,(t_2 - t_1) + t_2 - t}{L}$$

$$= \frac{\frac{W_1}{w}\,(t_2 - t_1) + t_2 - t}{1116 - 0{\cdot}71\,t}.$$

Professor Peabody's Throttling Calorimeter, fig. 8, consists of a chamber C, well clothed, to minimise as far as

possible the flow of heat through the walls. The vessel is fitted with a thermometer t and delicate pressure gauge G_2. The steam valve S is fully opened, and steam allowed to flow through until the instrument has acquired the temperature of the circulating steam in the chamber. The steam pressure in the chamber may be kept at about 12 lb. per square inch by the gauge G_2. The observations to be taken are pressure

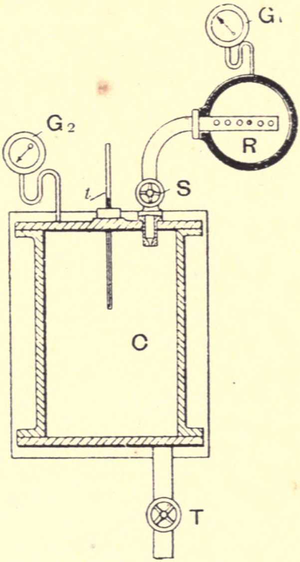


FIG. 8

of steam in chamber by gauge, and temperature of steam. A table of steam pressures and corresponding temperatures and total heat per pound will be required; also the barometric pressure should be noted at the time of the experiment, in order that the pressures may be expressed as absolute pressures.

Let H be the total heat (from 32 deg. Fah.) of 1 lb. of steam at the pressure in the calorimeter.

l be the heat of vaporisation at the pressure of steam in the pipe to be tested.

h be the heat in 1 lb. of water at the pressure of the steam in the pipe to be tested.

T be the degrees F given by calorimeter thermometer.

t be the temperature (ascertained from the tables) of steam at pressure corresponding to calorimeter gauge.

S be equal to $(T - t)$ = degrees of superheat.

X be the weight of dry steam in 1 lb. of steam and water collected from the sampling pipe.

$$X = \frac{H + 0{\cdot}4808\ S - h}{l}.$$

$$\text{The water will} = 1 - X = 1 - \frac{H + 0{\cdot}4808\ S - h}{l}.$$

As mentioned above, the limit of the instrument is reached when $T = t$—that is, when $S = 0$.

Example of a Boiler Trial.—Having described the apparatus necessary for conducting a boiler test, we shall now proceed to work out the results of such a test from the data given below.

From the log sheets the following averages have been obtained :—

1.	Duration of test	10 hours
2.	Total heating surface of boiler	1415 sq. ft.
3.	Grate area	40 sq. ft.
4.	Ratio $\frac{\text{heating surface}}{\text{grate area}}$	$\frac{35{\cdot}3}{1}$
5.	Temperature of outside air	65° F.
6.	Temperature of gases leaving heating surface of boiler	385° F.
7.	Temperature of feed water	60° F.
8.	Average steam pressure by gauge	85 lb. per sq. in.
9.	Feed water per hour (from feed tank)	4430 lb.
9A.	Water carried over with steam (from calorimeter)	88 lb.
9B.	Actual evaporation per hour	4342 lb.

10. Water evaporated per square feet heating surface	3·068 lb.
11. Weight of coal per hour as weighed at boilers	525 lb.
12. Weight of coal per hour as dry at boilers	506·63 lb.
13. Moisture in fuel estimated as percentage of wet coal	3·5 per cent
14. Ash and clinker drawn from furnace per pound of coal, wet.	0·0063
15. Ash per pound of wet coal per analysis	0.0056
16. Difference between unburnt carbon per pound of wet coal	0·0007
17. Weight of combustible burnt per hour	419 lb.
18. Calorific value per pound of coal, wet	13,294
19. Calorific value per pound of coal, dry	13,778
20. Pounds of dry coal fired per square foot of boiler heating surface per hour	0·358
21. Pounds of dry coal fired per square foot of grate area	12·66
22. Water evaporated per pound of coal under actual conditions	8·27
23. Equivalent evaporation from and at 212° F. (lb.)	9·71
24. Water evaporated per pound of dry coal	8·75
25. Equivalent evaporation per pound of dry coal from and at 212° F.	10·06
26. Water evaporated per pound of combustible burnt (lb.)	10·24
27. Equivalent evaporation from and at 212° F.	12·03
28. Weight of air required per pound of dry coal	11·06
29. Weight of gases per pound of coal at end of boiler heating surface by analysis of gases	27·8
30. Weight of excess of air per pound of dry coal	16·8
31. Analysis of furnace gases — CO_2	12·5
CO	0·0
O	6·4
N	81·1
32. Efficiency of boiler	83 per cent
33. Calorific value per pound of dry coal	13,778
34. Heat to water per pound of dry coal	11,467
35. Heat carried off in chimney gases	2,973
36. Heat required to evaporate moisture, per pound	40
37. Heat lost in unburnt carbon	10
38. Heat lost in ashes	12
39. Radiation unaccounted for, and error	203
40. Analysis of fuel — Carbon	75·3
Hydrogen	4·6
Moisture	3·5
Ash	5·6
Oxygen, nitrogen, and sulphur (by difference)	11·0
	100·0
41 Dryness fraction determined from calorimeter	98

Referring to line 6: The temperature of the gases leaving the heating surface of the boiler is sometimes difficult to obtain accurately. If a pyrometer be used it should remain

in the flue for about half an hour before any readings are taken, and it should be kept in position during the test. Sometimes a high-temperature glass thermometer may be used, in which case the bulb should be inserted in a sand bath, and the whole lowered into the flue upon an iron wire. The thermometer should be very quickly withdrawn and read off with the bulb immersed in the hot sand. If about 2 lb. of sand be used, the temperature will not be seriously affected in the time required to withdraw and read the thermometer.

9A. Calorimeter gave 2 per cent wetness, therefore

$$4430 \times \frac{2}{100} = \text{water not evaporated, } 88{\cdot}6 \text{ lb. per hour.}$$

12. The weight of coal, as weighed at the boiler, is given as 525 lb. per hour. Referring to the fuel analysis, there is 3·5 per cent of moisture. Some confusion may arise in the percentages being calculated on the dry or wet sample. In the fuel analysis the percentages are given on the total weight of the sample tested—that is, when charged with moisture. In the case before us, 3·5 lb. of water exist in 100 lb. of sample—namely, coal and water; therefore we must deduct $\frac{525}{100} \times 3{\cdot}5$ as the amount of water weighed with the coal. This equals 18·37 lb. and $525 - 18{\cdot}37 =$ 506·63 lb. of dry coal.

14. The total ash taken from the furnace is, of course, weighed. The stoker should be reminded that he must not slake the ash by turning water upon it, as he would do in the ordinary discharge of his duty. The weight of ash and clinker per pound of fuel is generally greater than that given by the analysis by the weight of unburnt carbon, which necessarily drops through the bars.

16. This is an important figure, inasmuch as it affords an excellent check on the suitability of the grate-bar air spaces, and also upon the traverse of the bars in the case of a mechanical stoker. In the latter case, it may happen that the bars convey the fuel to the ashpit before it is thoroughly reduced to ash. The importance of keeping the

bars well covered with fuel up to the end of the grate constitutes a temptation to allow unburnt fuel to be carried forward.

17. The sulphur in the fuel is usually neglected in estimating the weight of combustible. From the fuel analysis 79·9 per cent of the total weight of fuel is combustible. But some of the carbon was not burnt, therefore the actual weight of combustible, allowing for this, is 79·9 – 0·007 = 79·83 per cent. The actual weight of fuel used per hour (see 11) is 525, and the actual weight burnt is therefore $\frac{525}{100} \times 79{\cdot}83 = 419$ lb.

18. The calorific value in British thermal units per pound of coal should be obtained from a fuel calorimeter, and this should agree with the value given by Mahler's formula—namely, $14{,}650\ C + 62{,}100\ H - (5400\ O + N)$, C representing the carbon, H the hydrogen, and O and N the oxygen and nitrogen. If the calorimeter gives a different value, the mean of the two may be taken. It must not be supposed that the calorific value of the fuel can be obtained with a high degree of accuracy, because however carefully the samples may be collected, they are not truly representative of the mass of fuel burnt during a ten-hours test. Any error in determining the calorific value will affect the efficiency of the boiler, hence every possible care should be exercised in obtaining this figure. The formula given above is based upon a large number of calorimeter tests, and should therefore agree very closely with the experimental determination.

Calorific value = $(14650 \times 0{\cdot}753) + (62100 \times 0{\cdot}046) = (5400 \times 0{\cdot}110) = 11032 + 2856 - 594 = 13{,}294$ B.T.U.'s.

19. Allowing for wetness of fuel we have

$$13{,}294 \times \frac{100}{96{\cdot}5} = 13{,}778 \text{ B.T.U.}$$

22. The actual evaporation allowing for priming is here calculated.

23. To get the equivalent evaporation from and at 212 deg. Fah., the following data must be obtained : Pressure in

boiler = 85 lb. per square inch; the temperature of boiler feed water 60 deg. Fah.; composition of each pound of water disappearing from boiler—that is, 0·98 lb. of steam and 0·02 lb. of water (see steam calorimeter, 9A); the total heat required to evaporate 0·98 lb. of steam at 85 lb. boiler pressure; and the temperature of water in the presence of steam at 85 lb. per square inch boiler pressure (327 deg. Fah.).

Referring to a steam table, we find total heat of 1 lb. of steam at 85 lb. by gauge = 99·7 lb. absolute is given in table of properties of saturated steam (see *Practical Engineer* Pocket-book, page 126), 1182 units when the water is at 32 deg. Fah. The heat required per pound when the temperature of the feed is 60 will therefore be 1182 – (60 – 32) = 1154 units per pound. But of 1 lb. disappearing from the boiler only 0·98 is evaporated; therefore 1154 × 0·98 = heat required = 1130 (nearly). To this must be added the heat in 0·02 lb. of water at 327 deg. Fah. Degrees through which water is raised = 327 – 60 = 267; therefore heat taken up by 0·02 lb. = 2·67 × 0·02 = 5·34 units. 1130 + 5 = 1135 (neglect decimals) = heat transferred to each pound disappearing from the boiler. Now, if the feed water had been raised to 212 deg. Fah. by some independent source of heat before entering the boiler, and if at this temperature it were evaporated at atmospheric pressure, the heat required would be 966 units; hence, instead of each pound absorbing 1135 units, it requires a less quantity of heat, which is equivalent to saying that 1135 units would evaporate $\frac{1135}{966}$ lb. of water from and at 212 deg. Fah. To obtain the equivalent evaporation we must therefore multiply the feed water as measured by $\frac{1135}{966}$.

$$8{\cdot}27 \times \frac{1135}{966} = 9{\cdot}71.$$

25. $\dfrac{9{\cdot}71 \times 100}{96{\cdot}5}$ = equivalent evaporation from and at 212 per pound of dry coal = 10·06.

26. Water evaporated per pound of combustible

$$= 8{\cdot}27 \times \frac{525}{419} = 10{\cdot}24.$$

27. $10{\cdot}24 \times \dfrac{1135}{966} = 12{\cdot}03.$

28. Weight of air required per pound of dry coal is

$$= 12\ C + 36\left(H - \frac{O}{8}\right).$$

The ultimate analysis for oxygen is not given, and the error involved in neglecting the $\frac{O}{8}$ is not serious. For instance, suppose the O to be 8 per cent, we have $12 \times 0{\cdot}753 + 36\ (0{\cdot}046 - 0{\cdot}01) = 10{\cdot}65$ lb. Now, neglecting the O, we have 10·68 (for wet coal). That is, the error due to an assumption of a maximum quantity of oxygen only amounts to 3 in 1065, or 0·28 per cent.

$$10{\cdot}68 \times \frac{100}{96{\cdot}5}\ 11{\cdot}06 \text{ lb.}$$

of air per pound of dry coal.

29. If there were no excess of air, and the whole of the oxygen present combined with the carbon of the fuel, the percentage of CO_2 by volume in the furnace gases would be 21, leaving a nitrogen residue of 79 per cent. Owing, however, to the disappearance by condensation of the water formed by the combustion of the hydrogen in the fuel, the apparent volume of nitrogen in the constituents is usually about 81 per cent. The variation in the nitrogen residue affords some indication of the class of fuel. For instance, a fuel rich in hydrogen would lead to nitrogen residue of greater percentage. Conversely, a fuel containing very small traces of hydrogen—such, for instance, as when coke is used—the percentage of nitrogen residue would be nearer 79. The combination of oxygen with any sulphur there may be in the fuel, of course, tends to reduce the available volume of CO_2. From the experience of the writer, he believes that 81 per cent of nitrogen is an average residue. This

permits of a maximum possible percentage of CO_2 = 19 per cent, which figure diminishes as the volume of air increases. Assuming this value—viz., 19 per cent—as the maximum possible, then the excess of air will be found by

$$\frac{19}{\text{per cent } CO_2}.$$

In our present case this gives us

$$\frac{19}{12 \cdot 5} = 1 \cdot 54,$$

which means that we were using 1·54 time the air actually necessary. The air necessary we have already found to be 11·06 lb. per pound of fuel; hence the air used = 11·06 + (11·06 × 1·54) = 27·8 lb., and the excess per pound of dry coal will be 16·8.

32. Boiler efficiency = $\frac{\text{heat transferred to steam}}{\text{heat contained in fuel}}$. We have calculated that the water evaporated per pound of dry coal from and at 212 = 10·33 lb., and the heat contained in this, reckoned above the temperature of the feed = (1178 − 60) 10·33 = 1110 × 10·33 = 11,467. The heat available per pound of fuel (dry) = 13,778. Hence efficiency

$$= 100 \times \frac{11467}{13778} = 83 \cdot 2 \text{ per cent.}$$

35. The heat carried off in chimney gases = weight of products × temperature × specific heat. From 29 we have weight of products = 27·8 lb. Temperature from 6 = 385 deg. Fah. From this deduct temperature of outside air, 65 deg. Fah. Net temperature = 320 deg. Fah. Specific heat of furnace gases may be calculated from constituents, but for all ranges of constituents it will be found that the value varies only in the third decimal place, hence we may take 0 23 as constant. Heat lost in chimney gases

$$= 27 \cdot 8 \times 320 \times 0 \cdot 23 = 2046.$$

36. Heat required to evaporate moisture in the coal = weight of water evaporated per pound of coal × (total heat

of steam at pressure of air in furnace − temperature of outside air). From fuel analysis we get 0·035 lb. From draught = $\frac{1}{2}$ in. water = 0·5 × 0·036 = 0·16 lb. Barometric pressure − 0·16 = 14·7 − 0·16 = 14·54 lb. per square inch pressure in furnace. (For all practical purposes, with small draught it is near enough to neglect the draught.) Heat required to evaporate moisture

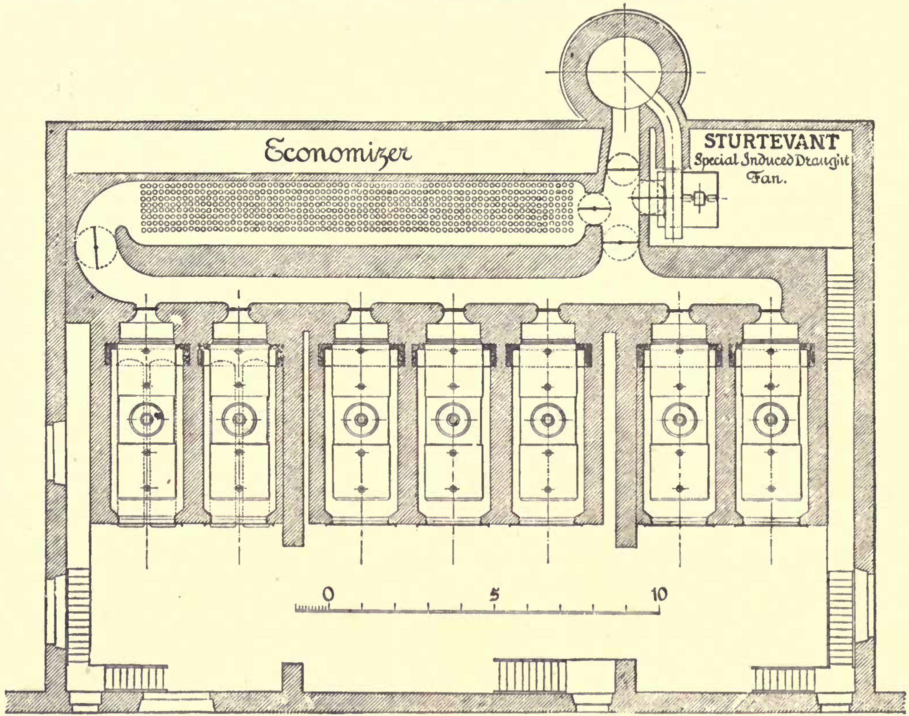
$$= 0{\cdot}035 \times (1177 - 65 \text{ deg.}) = 38{\cdot}9, \text{ say } 40.$$

37. 0·0007 × 14·650 = 10·255 units per pound.

38. To ascertain the heat lost in the ash and clinker, a piece should be plunged into water, the temperature of which is taken before and after cooling the clinker. The weight of water and clinker is ascertained. Suppose 3 lb. of clinker be put into 33 lb. of water directly the former is drawn from the bars. Let the temperature of water before and after be 85 and 103, then the rise in temperature = 18 deg., and heat given up per pound of clinker = $\frac{18}{3} \times 33 = 198$ units per pound of ash. Therefore, per pound of dry coal we have

$$19{\cdot}8 \times 0{\cdot}056 \times \frac{100}{96{\cdot}5} = 11{\cdot}4, \text{ say } 12.$$

39. The radiation and error usually amount to 10 per cent, though in some instances, with boilers entirely covered with brickwork, there is very little radiation.


Economizer
STURTEVANT
Special Induced Draught Fan.
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— Croton —